Measurement of Orbitally Excited D-Mesons at CDF II

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1 – Outline

- √ D_J Mesons: Short Introduction.
- √ Experimental Status.
- √ CDF Experimental Procedure.
  - Data Sample and Triggers.
  - Requirements and Reconstruction of D- Mesons.
  - Control of a Calibration.
- √ $D_J^0 \to D^{*+}\pi^-$ Mode.
- √ $D_J^0 \to D^+\pi^-$ Mode.
- √ Results.
- √ Conclusions.

2 – Introduction

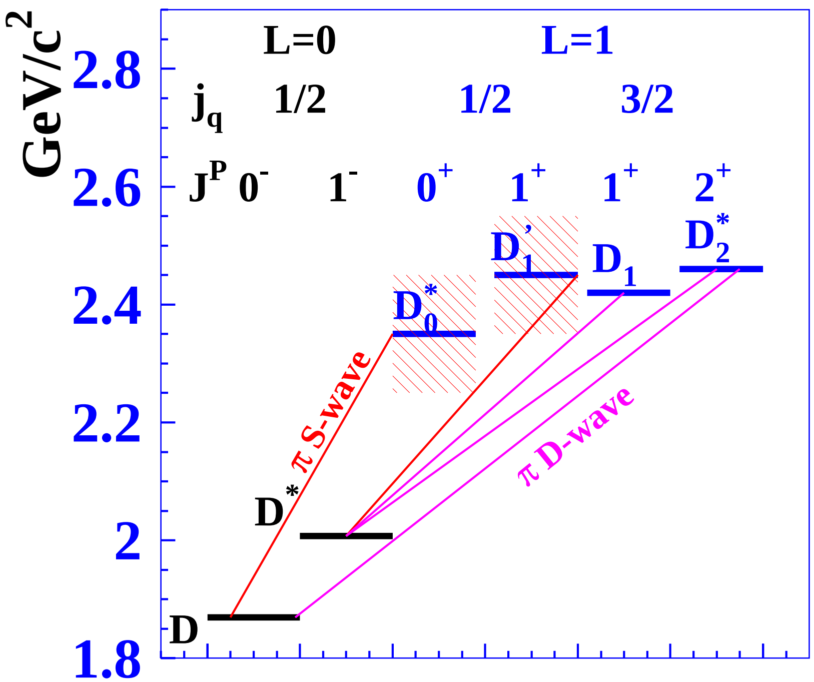
Many properties of hadrons composed from a single heavy quark Q can be simplified substantially in the large heavy quark mass limit $m_Q \rightarrow \infty$. With $m_Q \gg \Lambda_{QCD}$ the degrees of freedom of the light quark system become insensitive to the mass m_Q and the heavy quark acts simply as a non recoiling source of color. This approach was abbreviated as **H.Q.E.T. models.** $\Rightarrow$ In **HQET** Charm D-mesons $\mathbf{\bar{q}Q}$ can be treated as a quark "hydrogen atom":

- heavy charm quark spin $s_Q = \frac{1}{2}^+$ **decouples** from light quark degrees of freedoms.
- the light anti-quark spin-parity $s_q = \frac{1}{2}^-$ couples with its orbital momentum L .
- $\vec{j_q} = \vec{s_q} + \vec{L}$ is a good quantum number.
- $\vec{J} = \vec{j_q} + \vec{s_Q}$ is a total momentum.

$\Rightarrow$ **Consider L=1, D-mesons:**

- $J = \frac{1}{2}^+ \oplus \frac{1}{2}^+$ or
  - $\mathbf{D'_1}$ **meson,** $\mathbf{1^+}$ $(\mathbf{^1P_1})$ **and** $\mathbf{D_0^*}$ **meson,** $\mathbf{0^+}$ $(\mathbf{^1P_0})$.
- $J = \frac{3}{2}^+ \oplus \frac{1}{2}^+$ or
  - $\mathbf{D_1}$ **meson,** $\mathbf{1^+}$ $(\mathbf{^3P_1})$ **and** $\mathbf{D_2^*}$ **meson,** $\mathbf{2^+}$ $(\mathbf{^3P_2})$.
- As m_Q is large, **but not infinite**, $\vec{j_q} - \vec{s_Q}$ interaction splits the mass states within these doublets.

$\Rightarrow$ $S-$ **and** $P-$**wave multiplets of D-mesons:**



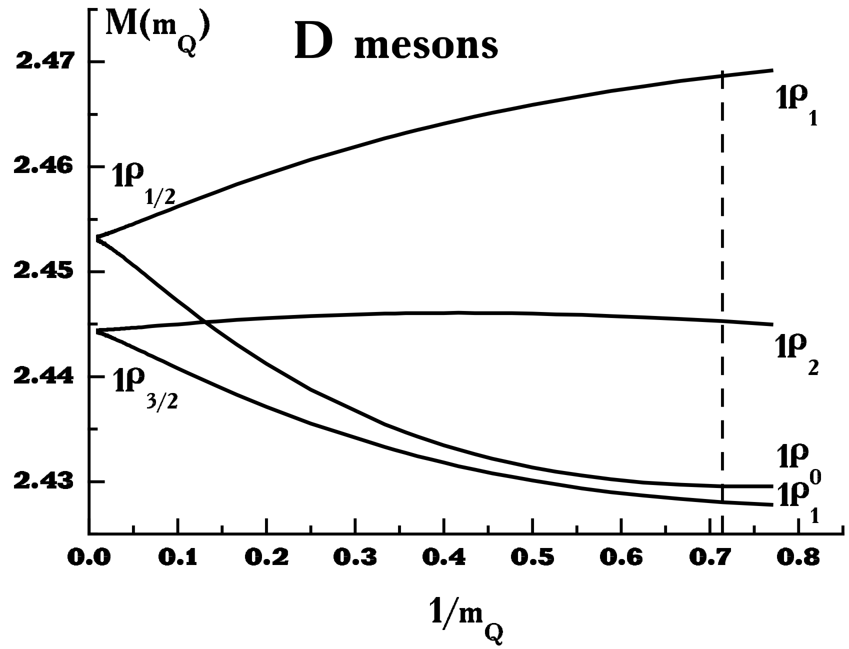
$\Rightarrow$ *this nice picture has been copied from hep-ex/0307021, courtesy of BELLE Collab.*

$\Rightarrow$ **... and their possible decay modes:**

- **strong decays** with emission of π, 0^-
  - $\mathbf{P}-$parity and $\mathbf{I}-$ are conserved.
- $\frac{1}{2}^+ \to \frac{1}{2}^- + 0^-$,
  π emitted in $S-$wave, $L = 0$.
  - broad $\Gamma_{theor.} \sim 170 - 990\,\mathrm{MeV}$
  - $\mathbf{D'_1} \to \mathbf{D}^*\pi$, $1^+ \to 1^- + 0^-$
  - $\mathbf{D_0^*} \to \mathbf{D}\pi$, $0^+ \to 0^- + 0^-$
- $\frac{3}{2}^+ \to \frac{1}{2}^- + 0^-$,
  π emitted in $D-$wave, $L = 2$.
  - narrow $\Gamma_{theor.} \sim 15 - 45\,\mathrm{MeV}$
  - $\mathbf{D_1} \to \mathbf{D}^*\pi$, $1^+ \to 1^- + 0^-$
  - $\mathbf{D_2^*} \to \mathbf{D}\pi$, $2^+ \to 0^- + 0^-$
  - $\mathbf{D_2^*} \to \mathbf{D}^*\pi$, $2^+ \to 1^- + 0^-$
- $\mathbf{D'_1}$, $\mathbf{D_1}$ states are mixed.

⇒ Yu.S.Kalashnikova, A.V.Nevediev in Phys.Lett. B530(2002)117 [hep-ph/0112330] used another approach – QCD string with quarks at the ends:

- D_J mass splittings in P-wave multiplets.



⇒ One has to mention here about a limited range of theoretical predictions of HQET, string or other models.

⇒ The recent discoveries of $\mathbf{D_s(2317)}$, $\mathbf{D_s(2457)}$ pose a challenge for these theoretical approaches (see e.g. tomorrow a talk by Alexei Droutskoy, BELLE).

3 – Experimental Status

⇒ The experimental study was pioneered by ARGUS in 1985 with a discovery of a $D_1(2420)^0,\ 1^+$ state.

⇒ **This talk presents a study on P-wave neutral $\mathbf{D_J^0}$-mesons in $\mathbf{D^+\pi^-, D^{*+}\pi^-}$.**

Group	State	Mode	Mass, MeV/c^2	Γ, MeV/c^2
CLEO94	D_2^{*0}	$D^+\pi^-$	2465$\pm$3$\pm$3	$28^{+8}_{-7}\pm 6$
BELLE03	D_2^{*0}	$D^+\pi^-$	2461.6$\pm$2.1$\pm$3.3	45.6$\pm$4.4$\pm$6.7
FOCUS04	D_2^{*0}	$D^+\pi^-$	2464.5$\pm$1.1$\pm$1.9	38.7$\pm$5.3$\pm$2.9
CLEO94	D_1^0	$D^{*+}\pi^-$	$2421^{+1}_{-2}\pm 2$	$20^{+6}_{-5}\pm 3$
BELLE03	D_1^0	$D^{*+}\pi^-$	2421.4$\pm$1.5$\pm$0.9	23.7$\pm$2.7$\pm$4.0
CLEO99	D'^0_1	$D^{*+}\pi^-$	$2461^{+41}_{-34}\pm 34$	$290^{+101}_{-79}\pm 44$
BELLE03	D'^0_1	$D^{*+}\pi^-$	2427$\pm$26$\pm$25	$384^{+107}_{-75}\pm 74$
BELLE03	D_0^{*0}	$D^+\pi^-$	2308$\pm$17$\pm$32	276$\pm$21$\pm$63
FOCUS04	D_0^{*0}	$D^+\pi^-$	2407$\pm$21$\pm$35	240$\pm$55$\pm$59

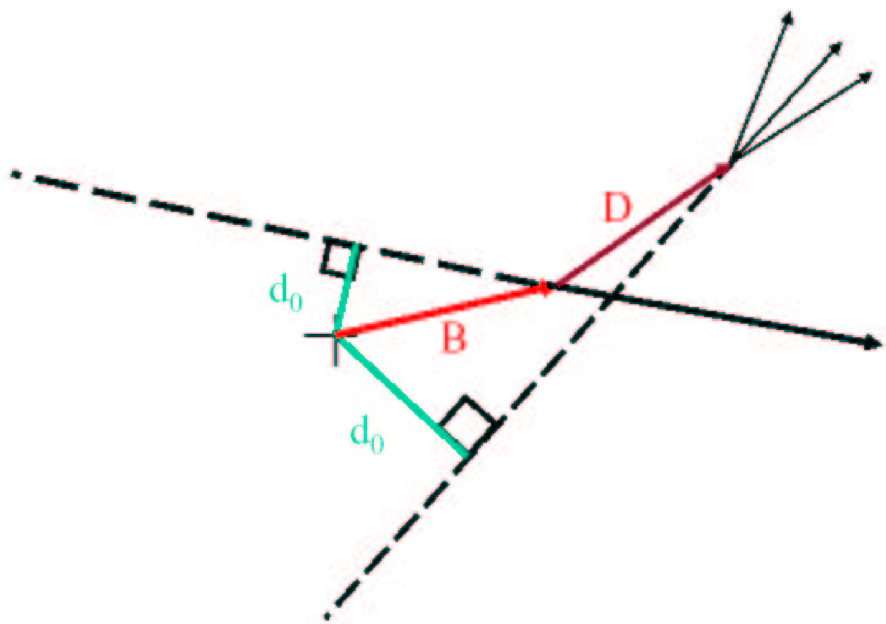
4 – CDF Data Sample and Triggers.

$\Rightarrow$ Impact Parameter Two Track Trigger:

- Level 1 eXtremely Fast Tracker (XFT) with COT detector.
  - $p_T^{1,2} > 2.0\, GeV/c$
  - $p_T^1 + p_T^2 > 5.5\, GeV/c$
- Level 2 Silicon Vertex Tracker (SVT), impact parameter requirements:

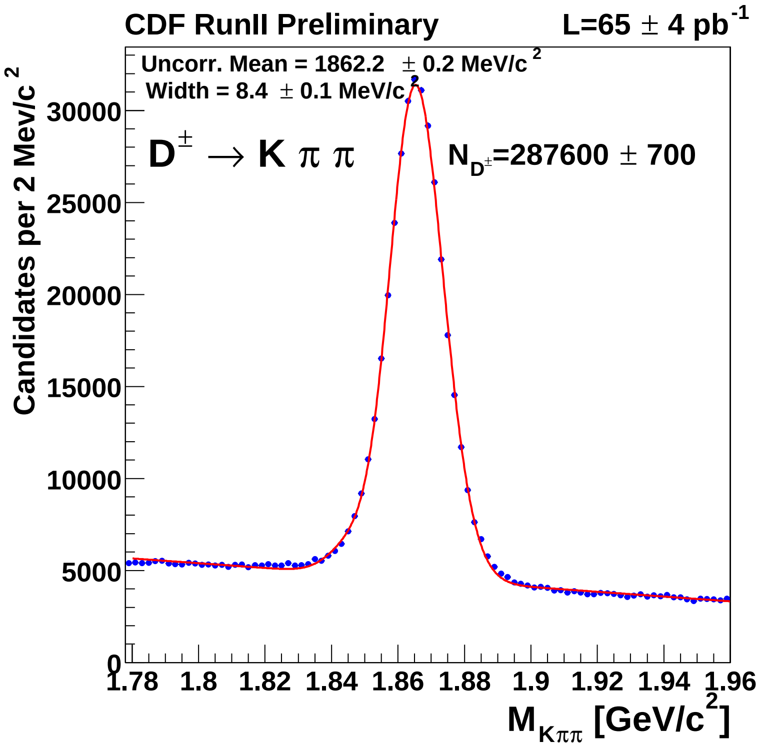
  $\Rightarrow\ 1000\mu\, m\ >\ d_0^{1,2}\ >\ 120\mu\, m$
- impact parameter resolution by CDF Si detector

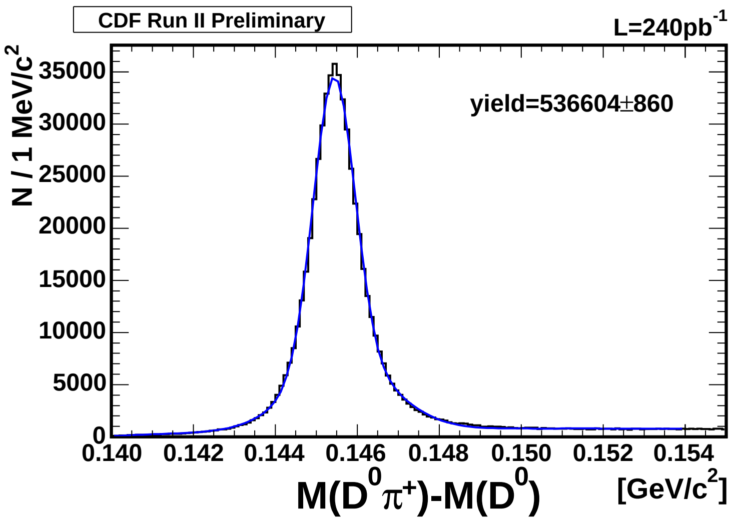
  $\sigma(\mathrm{d}_0) = \sigma_{\mathrm{beam}} \oplus \sigma_{\mathrm{Si\,Resol}} = 48\mu\mathrm{m}$
- At a Level 3: a full event reconstruction.



CDF 'Silicon Vertex Tracking' trigger: displaced track requirements.

- The trigger allowed to collect large samples of D^0, D^+, D^{*+}.
- $\sim$0.5M D^{*+} with present $\mathcal{L} \sim 210\ pb^{-1}$.





$$\delta M(D^{*+}, D^0) = 145.4\, MeV/c^2$$
$$\sigma(\delta M(D^{*+}, D^0)) \sim 0.5\, MeV/c^2$$

- Two Track Trigger: Rich physics in Charm and Beauty sector.
- **Competitive data samples for studies of a P-wave D-meson multiplet.**

5 – Analysis of $\mathrm{D}^{*+}\pi^-$ and $\mathrm{D}^{+}\pi^-$ Mass Spectra

$\mathbf{D^0_J \rightarrow D^{*+}\pi^-_{dec}, D^{*+} \rightarrow D^0\pi^+_{soft},}$
$\mathbf{D^0 \rightarrow K^-\pi^+} +$ chrg.conj.combs.

- Both D_1^0, D_2^{*0} do contribute to final
- The 2 hardest tracks of 4, e.g. $D^0 \rightarrow K^-\pi^+$, trigger the event and match the trigger information offline.
- The 4-track combination is subjected to the 2D-Vx fit offline, no mass constr-s.
- $\chi^2_{r-\phi}$(VxFit) < 30 and L_{xy}(Vx) $> 500\mu m$
- "$D^0(K^-\pi^+)$" $\in M(D^0) \pm 3\sigma$
- $\delta M = M($"D^0" $\pi^+_{soft}) - M($"D^0"$)$
- "$D^{*+}(D^0\pi^+_{soft})$" $\in \delta M(D^{*+}) \pm 3\sigma$

$\mathbf{D^0_J \rightarrow D^{+}\pi^-_{dec}, D^{+} \rightarrow K^-\pi^+\pi^+} +$ chrg.conj.combs.

- Only D_2^{*0} does contribute.
- D^+ signal has higher background – apply harder cuts.
- The 3D-Vx fit of 4-tracks and
- χ^2_{3D}(VxFit) < 12 and L_{xy}(Vx) $> 1000\mu m$
- "$D^+(K^-\pi^+\pi^+)$" $\in M(D^+) \pm 3\sigma$
- $P_T^{\pi^-} > 800 MeV/c, \pi^- \in D^+\pi^-_{dec}$

$\Rightarrow$ **Work with mass difference spectra:**

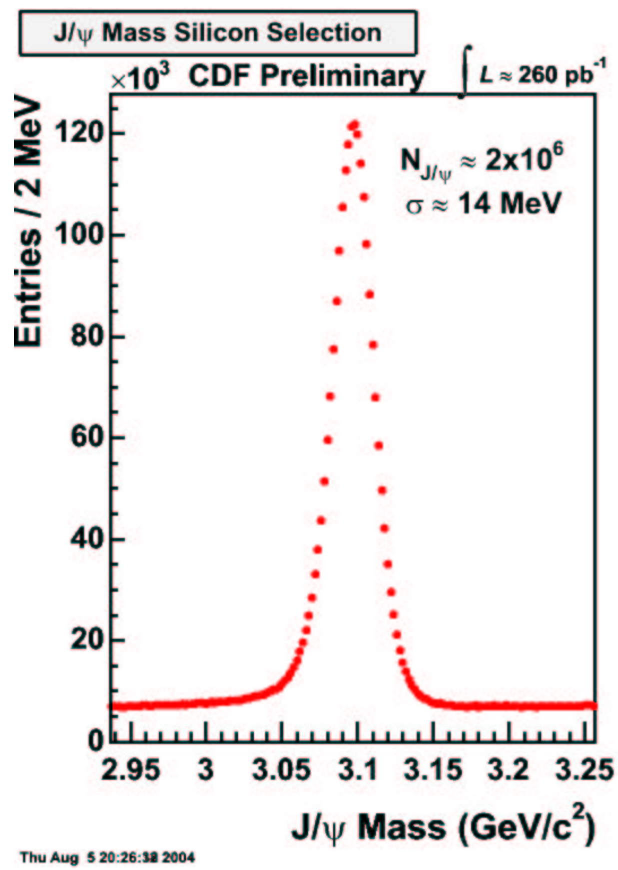
$\Rightarrow \mathbf{\Delta M = M(D^{(*+)\,or\,(+)}\pi^-_{dec}) -}$

$\Rightarrow \mathbf{M(D^{(*+)\,or\,(+)})}$

6 – Tracking Calibration.

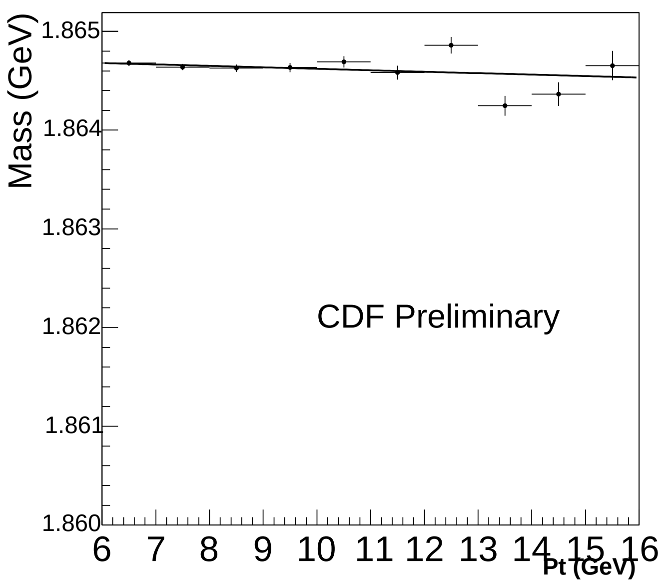
$\Rightarrow$ A precise measurement of masses requires a very good control on the calibration of the tracking system made with $J/\Psi \to \mu^+\mu^-$ and $K_s^0 \to \pi^+\pi^-$.

- The excellent mass resolution was achieved using a J/Ψ signal as a calibrating reference.
- A good knowledge of a magnet field...
- and of an amount of a dead material in Si tracker is required.
- The yield is $N_{evts} = 2 \cdot 10^{+6}$of J/Ψ.
- ...and the $\sigma \sim 14\,\mathrm{MeV/c^2}$.



$\Rightarrow$ **Checkout the calibration with our basic final states, D^0, D^*+ and D^+:**

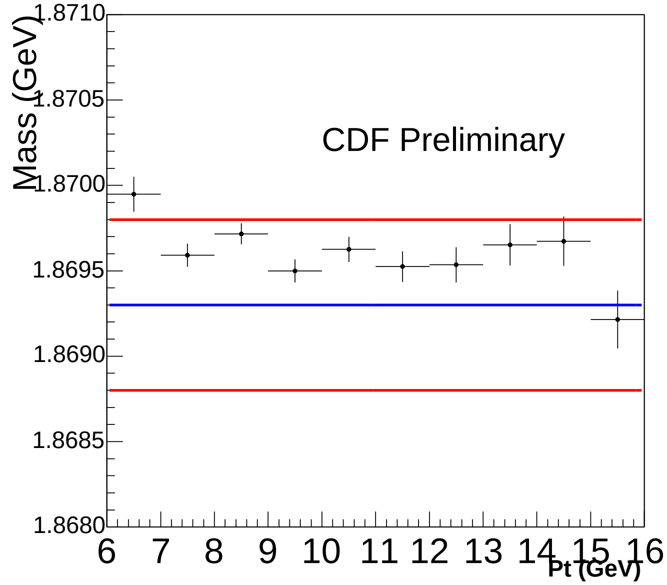
$\Rightarrow$ $M(D^0)_{meas.}$ stability as a function of P_T.



$$M(D^0_{pdg}) = 1864.6 \pm 0.5 MeV/c^2$$

$$\mathbf{M(D^0)_{meas.} \in M(D^0)_{pdg} \pm 1\sigma_{pdg}}$$

$\Rightarrow$ $M(D^+)_{meas.}$ stability as a function of P_T.



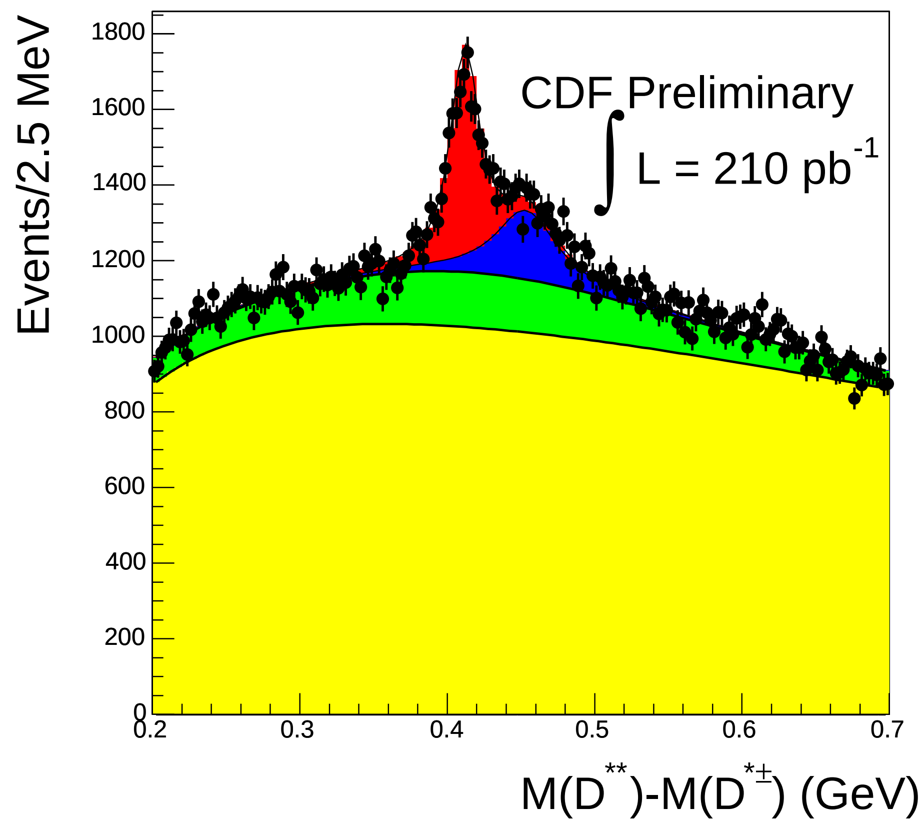
$$M(D^+_{pdg}) = 1869.3 \pm 0.5 MeV/c^2$$

$$\mathbf{M(D^+)_{meas.} \in M(D^+)_{pdg} \pm 1\sigma_{pdg}}$$

7 – Mass Difference Spectra for $\mathrm{D}^{*+}\pi^-$ and $\mathrm{D}^+\pi^-$ Modes.

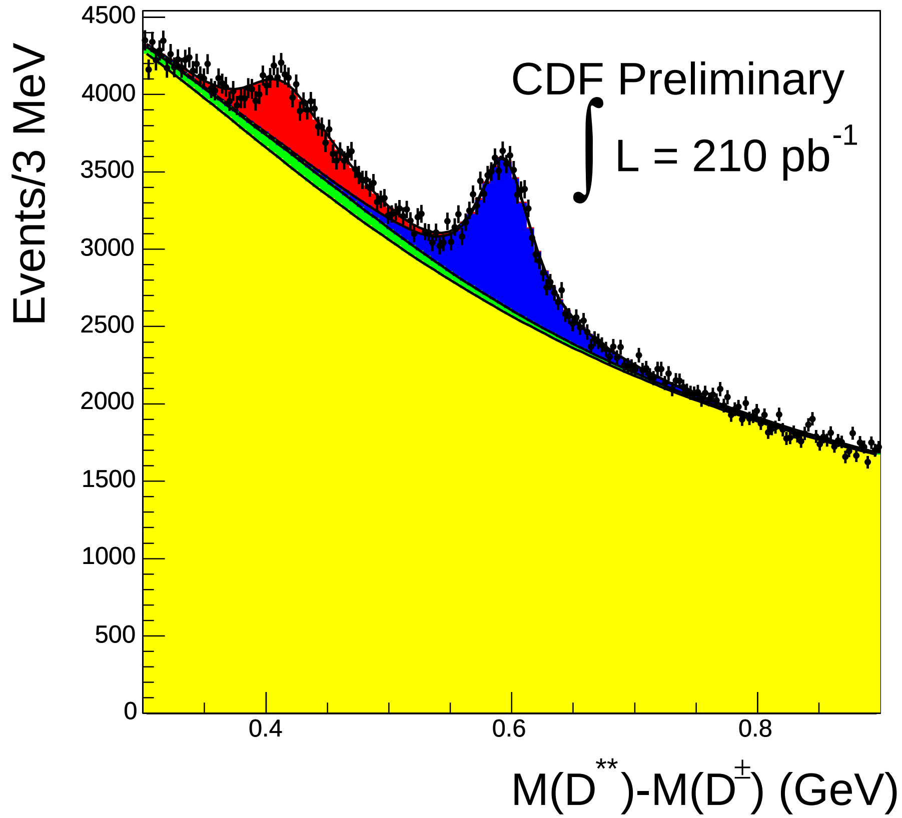
$\Rightarrow$ **Plot** $\mathbf{\Delta M = M(``D^{*+}``\pi^-_{dec}) - M(``D^{*+}``)}$

- Two peaks corresponding to narrow resonances:
  - $\Delta M(D_1(2420)^0) \sim 410\, MeV/c^2$,
  - $N(D_1^0)$ ~7000 evts.
  - $\Delta M(D_2^*(2460)^0)) \sim 450\, MeV/c^2$,
  - $N(D_2^{*0})$ ~4000 evts.
- The possible contribution of a broad D'^0_1 component
- Large combinatoric background



$\Rightarrow$ **Plot $\mathbf{\Delta M = M(``D^+``\pi^-_{dec}) - M(``D^+``)}$**

- Two visible bumps can be attributed to:
  - $\Delta M(D_2^*(2460)^0)) \sim 600\,MeV/c^2$,
  - structure $\Delta M \sim 400\,MeV/c^2$, feed-downs from both $D^{*+}\pi^-$ states, when $D^{*+} \to D^+\pi^0,\ BR \sim 31\%$, π^0 goes undetected.
- The possible contribution of a broad D_0^{*0} component.
- Again large combinatoric background.



8 – Fits of Mass Difference Spectra

$\Rightarrow$ Both ΔM histograms have been fitted simultaneously. The likelihood function used has independent background and broad state $\Delta M(D'^0_1 \; or \; D^{*0}_0)$ terms, while the same values for $\Delta M(D^0_1 \; or \; D^{*0}_2)$ and $\Gamma(D^0_1 \; or \; D^{*0}_2)$

- $Bgr(\Delta M) = a \cdot \Delta M^b \cdot \exp(-\Delta M) \cdot c \cdot \sqrt{\Delta M - m_\pi} + Const(D^+\pi^- \text{mode only})$
- The broad and narrow resonances and feed-downs are described by $\mathcal{BW} \oplus Gaussian$.
- The resolutions σ for $Gaussian$ have been obtained from extensive MC studies and **fixed in the fits**.

- The fit has been tested with MC sample of $\times 2$ larger size than data.
- **No selection biases have been observed.**
- The corresponding statistical uncertainty of fits of MC samples contributes into a systematics.
- The broad states masses and widths have been fixed to the PDG (D'^0_1) or the most recent measurements (D^{*0}_0).

9 – Neutral ^3P Charmed Mesons Mass and Width Results.

$\Rightarrow$ **The experimental numbers:**

- $\mathbf{M(D_1^0) - M(D^{*+}) = 411.7 \pm 0.7 \pm 0.4\,MeV/c^2}$
- $\mathbf{M(D_1^0) = 2421.7 \pm 0.7 \pm 0.6\,MeV/c^2}$
- $\mathbf{\Gamma(D_1^0) = 20.0 \pm 1.7 \pm 1.3\,MeV/c^2}$
- $\mathbf{M(D_2^{*0}) - M(D^{*+}) = 594.0 \pm 0.6 \pm 0.5\,MeV/c^2}$
- $\mathbf{M(D_2^{*0}) = 2463.3 \pm 0.6 \pm 0.8\,MeV/c^2}$
- $\mathbf{\Gamma(D_2^{*0}) = 49.2 \pm 2.1 \pm 1.2\,MeV/c^2}$

⇒ **The experimental numbers to be compared with other measurements:**

Group	State	Mode	Mass, MeV/c^2	Γ, MeV/c^2
CLEO94	D_2^{*0}	$D^+\pi^-$	2465$\pm$3$\pm$3	28$^{+8}_{-7}\pm$ 6
BELLE03	D_2^{*0}	$D^+\pi^-$	2461.6$\pm$2.1$\pm$3.3	45.6$\pm$4.4$\pm$6.7
FOCUS04	D_2^{*0}	$D^+\pi^-$	2464.5$\pm$1.1$\pm$1.9	38.7$\pm$5.3$\pm$2.9
PDG04	D_2^{*0}	$D^{(*+\ or\ +)}\pi^-$	2458.9$\pm$2.0	23$\pm$ 5
CDF II	$\mathbf{D_2^{*0}}$	$\mathbf{D}^+\pi^-$	**2463.3$\pm$0.6$\pm$0.8**	**49.2$\pm$2.1$\pm$1.2**
CLEO94	D_1^0	$D^{*+}\pi^-$	2421$^{+1}_{-2}\pm$ 2	20$^{+6}_{-5}\pm$3
BELLE03	D_1^0	$D^{*+}\pi^-$	2421.4$\pm$1.5$\pm$0.9	23.7$\pm$2.7$\pm$4.0
PDG04	D_1^0	$D^{*+}\pi^-$	2422.2$\pm$ 1.8	18.9$^{+4.6}_{-3.5}$
CDF II	$\mathbf{D_1^0}$	$\mathbf{D}^{*+}\pi^-$	**2421.7$\pm$0.7$\pm$0.6**	**20.0$\pm$1.7$\pm$1.3**

⇒ **The systematics comes from:**

- MC statistics determining the uncertainty of fits and Broad states mass and width assignments(the largest contribution), COT tracker ionization corrections, Magnet B-field and PDG masses **uncertainties**.

10 – Conclusions

- **CDF II Collaboration has presented the first measurements of neutral P-wave $\mathbf{D_1^0}$ and $\mathbf{D_2^{*0}}$ charmed mesons produced at hadron collider Tevatron.**

- **Thanks to a wonderful CDF tracking the measurements are of the best statistical and systematical uncertainties available now at the HEP market.**

- **The mass measurements of the states are in good agreement with world data.**

- **While $\mathbf{\Gamma(D_1^0)}$ is in a good agreement with world data, $\mathbf{\Gamma(D_2^{*0})}$ is in a good 1σ agreement with BELLE03 and FOCUS04 but does quite differ from PDG 2004 average value. This difference might provide an interesting input to theoretical developments. ;-)**

THE END OF THE TALK.